Currents in Rivers Observed by Spaceborne Along-Track InSAR – CuRiOSATI –

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LONG-TERM GOALS

The long-term goal of this project is the establishment of receiving, processing, and interpretation capabilities for spaceborne along-track interferometric synthetic aperture radar (along-track InSAR, ATI) data at the University of Miami's Center for Southeastern Tropical Advanced Remote Sensing (CSTARS) for high-resolution surface current field mapping with special emphasis on applications in estuarine environments and rivers.

OBJECTIVES

Within the project period of 24 months, which started officially in March 2009, we will

- acquire series of ATI images of selected test sites;
- implement ATI raw data processing capabilities at CSTARS;
- develop a robust current retrieval algorithm for rivers, which will correct the ATI-derived Doppler velocities for contributions of wave motions;
- compare the results with available reference data;
- evaluate the data quality in view of known user requirements; and
- evaluate the potential of dedicated ATI satellite missions with optimized instrument, platform, and orbit parameters for nearshore, estuarine, and river observations.

The main satellite to be used is the German TerraSAR-X, but we expect to obtain ATI data from other satellites as well, such as TanDEM-X, RADARSAT-2, and the Italian COSMO-SkyMed satellite constellation.

APPROACH

The product consists of five main tasks, which are defined as follows.

Task 1: Data Acquisition. Test sites of interest are selected, taking into account requirements of ONR and its existing programs, the suitability of the test sites for ATI data acquisitions and for the tests to be performed, and the availability of reference data for validation of the results. TerraSAR-X ATI images of the test sites are acquired repeatedly

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during a period of several months. At the beginning this is done in close collaboration with Hartmut Runge and Ulrich Steinbrecher at DLR Oberpfaffenhofen (Germany), who order the experimental data products and program the instrument for the individual data acquisitions, respectively. At a later stage, the ordering of ATI data acquisitions with TerraSAR-X will be possible through the Web interface that is also used for ordering conventional data products by regular PIs of TerraSAR-X. Furthermore, CSTARS is building up its own data ordering system for TerraSAR-X and will obtain direct access to the satellite in 2010. As a secondary activity, Task 1 includes the collection of reference data from in-situ measurements, numerical models, and existing data bases. We obtain such data from colleagues at other research institutions and agencies.

Task 2: Raw Data Processing. The ATI raw data need to be processed into complex SAR images, and some additional processing steps (co-registration etc.) need to be applied to obtain the phase images required for current retrievals. For the experimental images obtained so far, this has been done by Steffen Suchandt at DLR Oberpfaffenhofen (Germany). We will try to obtain his software for use at CSTARS at a later stage. This project makes an important contribution to the establishment of ATI data receiving and processing capabilities at CSTARS.

Task 3: Current Retrieval. The conversion of ATI phase images into actual line-of-sight current fields requires an application of advanced filtering techniques and a correction of detected Doppler velocities for contributions of wave motions and their spatial variations due to wave-current interaction, as theoretically discussed and partly demonstrated in previous publications [1][2][3][4]. The ATI-derived current fields from the Shuttle Radar Topography Mission (SRTM) in [3] and [4] were not corrected by this method because they were not absolutely calibrated, thus the mean contribution of wave motions could not be separated from other contributions that were not known theoretically. The absolute bias of the detected velocities had to be tuned by different methods. This will not be necessary with TerraSAR-X data, but some theoretical model and algorithm improvements will be required for river applications, since the computation of spatially varying wave contributions to Doppler velocities is a different problem for a river than for open waters. The model must be upgraded to account for shallow-water effects and boundary effects such as wave refraction, reflection, and dissipation at river banks. All filtering and correction of the ATI data and the development of model improvements is done by PI Roland Romeiser. In addition, an algorithm for direct wind retrievals from the amplitudes of TerraSAR-X SAR / ATI images, based on the one described in [5], will be implemented to eliminate the need for wind data from external sources. This is done in collaboration with Jochen Horstmann of NURC, La Spezia (Italy).

Task 4: Evaluation. The ATI-derived surface current fields must be checked for consistency and compared with available reference data to determine the achievable data quality under varying conditions (wind speed / surface roughness, river width, angles between flow direction, wind direction, and radar look direction, etc.). Based on the results, the suitability of the method for various applications will be discussed, and the potential of dedicated spaceborne ATI missions with optimized instrument and orbit parameters for ocean and river applications will be evaluated.

Task 5: Dissemination. The results obtained at different stages of the project will be disseminated through a project website, periodic progress reports to ONR (such as this one), presentations at informal meetings as well as national and international conferences, and at least two publications in peer-reviewed journals. To ensure an efficient collaboration and data exchange with existing ONR program teams and other potential partners and users, we have contacted these colleagues in an early stage of the project and informed them about our objectives, plans, and needs.

WORK COMPLETED

Task 1: Data Acquisition. First TerraSAR-X ATI images of ocean and river scenes were acquired in Aperture Switching (AS) mode in spring and summer 2008, including six images of the Elbe river (Germany), which were made available to us in December 2008. In spring 2009, another set of images of the Elbe river was acquired in Dual Receive Antenna (DRA) mode. In Fall 2009, the acquisition of AS-mode images was continued. After the Elbe river, a second river which will now be observed is the Lena river in Siberia. The Elbe river was selected as first test site a long time ago because we had experiences with it from the analysis of SRTM data [4], and it was easy to obtain additional reference data from governmental agencies. The Lena river has strong seasonal variabilities in its runoff (minimum 1400 m^3/s in April, maximum 74,000 m^3/s in June), and it is covered with ice for several months in winter. Reference data are available from a station. We are planning to acquire series of images of two major rivers in the U.S. in 2010. The implementation of receiving capabilities for TerraSAR-X, COSMO-SkyMed, and RADARSAT-2 at CSTARS is under way and expected to be completed at the end of 2009.

Task 2: Raw Data Processing. The first six TerraSAR-X AS-mode images of the Elbe river were processed in December 2008. An analysis revealed some artifacts in the data that could be attributed to suboptimal processing parameters. Improved results were obtained in September 2009. Also the DRA-mode images from spring 2009 were processed, but the data acquisition and processing procedures for this data product, which is theoretically superior to the AS-mode product (wider swath, less noise, no problems with certain processing artifacts that affect AS-mode data), are currently being revised by DLR due to unexpected drifting of a calibration parameter.

Task 3: Current Retrieval. Using the first six TerraSAR-X AS-mode images of the Elbe river, specific filtering and correction algorithms for TerraSAR-X data were developed. These algorithms can identify and eliminate phase signatures of ships and other strong scatterers in the water with nonrepresentative velocities, reduce the effect of azimuth ambiguities (ghost images of strong scatterers on land over water), correct the absolute phase calibration on the basis of phases measured over land, reduce remaining phase noise by filtering, convert, ATI phases into radial velocities, and correct the velocities for contributions of wave motions. This works pretty well, but as expected, our existing numerical model seems to overestimate the contributions of wave motions to ATI signatures of rivers. The development of model improvements is under way.

Task 4: Evaluation. A comparison of the first Elbe river results with current fields from a numerical model and station data showed relatively good overall agreement, but our existing ATI model seems to overestimate the required corrections for wave motions. Best results were obtained by reducing the model-derived corrections by 50%. In addition to this, the images processed in December 2008 exhibited pronounced artifacts that were attributed to ghost signatures of targets on land over water. This problem is significantly reduced in the reprocessed data obtained in September 2009. The results obtained so far indicate that our internal performance goal of a current measuring accuracy of 0.1 m/s at an effective spatial resolution better than 1000 m with TerraSAR-X can be met.

Task 5: Dissemination. The first TerraSAR-X results were presented in a press release of RSMAS and reproduced on several web sites. A full manuscript was accepted for publication in IEEE Trans. Geoscience Remote Sensing in August 2009 [6]. Furthermore, this work was presented at Oceans 2009 in Bremen, Germany [7], at the 2009 ONR Physical Oceanography Review Symposium in Chicago, and at the 2009 International Geoscience and Remote Sensing Symposium (IGARSS) in Cape Town, South Africa [8].

RESULTS

The six first TerraSAR-X ATI images, derived current fields, reference current fields from a numerical model, and a comparison of mean values are shown in Figs. 1-5. This is the main result obtaines so far, together with the algorithms developed to obtain it. We have learned from this first experiment how to process and correct the data. The results indicate that the expected data quality can be obtained and that TerraSAR-X is indeed well suited for current measurements in rivers, despite its clearly suboptimal system parameters. TerraSAR-X ATI data obtained in the future can be processed with the same algorithms. We are looking forward to the application of this technique to other rivers and to the planned ATI imaging model improvements that will permit a more accurate correction of ATI-derived velocity fields in rivers for contributions of wave motions.

IMPACT/APPLICATIONS

The availability of techniques for satellite-based current measurements in rivers will be relevant for a variety of applications in oceanography, climate research, hydraulic engineering, drinking water and flood risk management, and other disciplines. For DoD operations, the navigability of rivers (depth and current maps) and the monitoring and prediction of flooding events and changes in the water supply for major cities and agricultural regions are relevant. For technical, economical, or political reasons, available information on many rivers outside the U.S. and Europe is very limited. The use of satellite-based monitoring techniques is the most promising approach for overcoming this problem.

RELATED PROJECTS

The techniques developed here will be useful for other ONR-funded projects; in particular the new DRI "Inlet and River Mouth Dynamics" for which we have submitted a remote sensing proposal. Plans for more ATI-based projects at RSMAS / CSTARS exist.

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PATENTS

None.

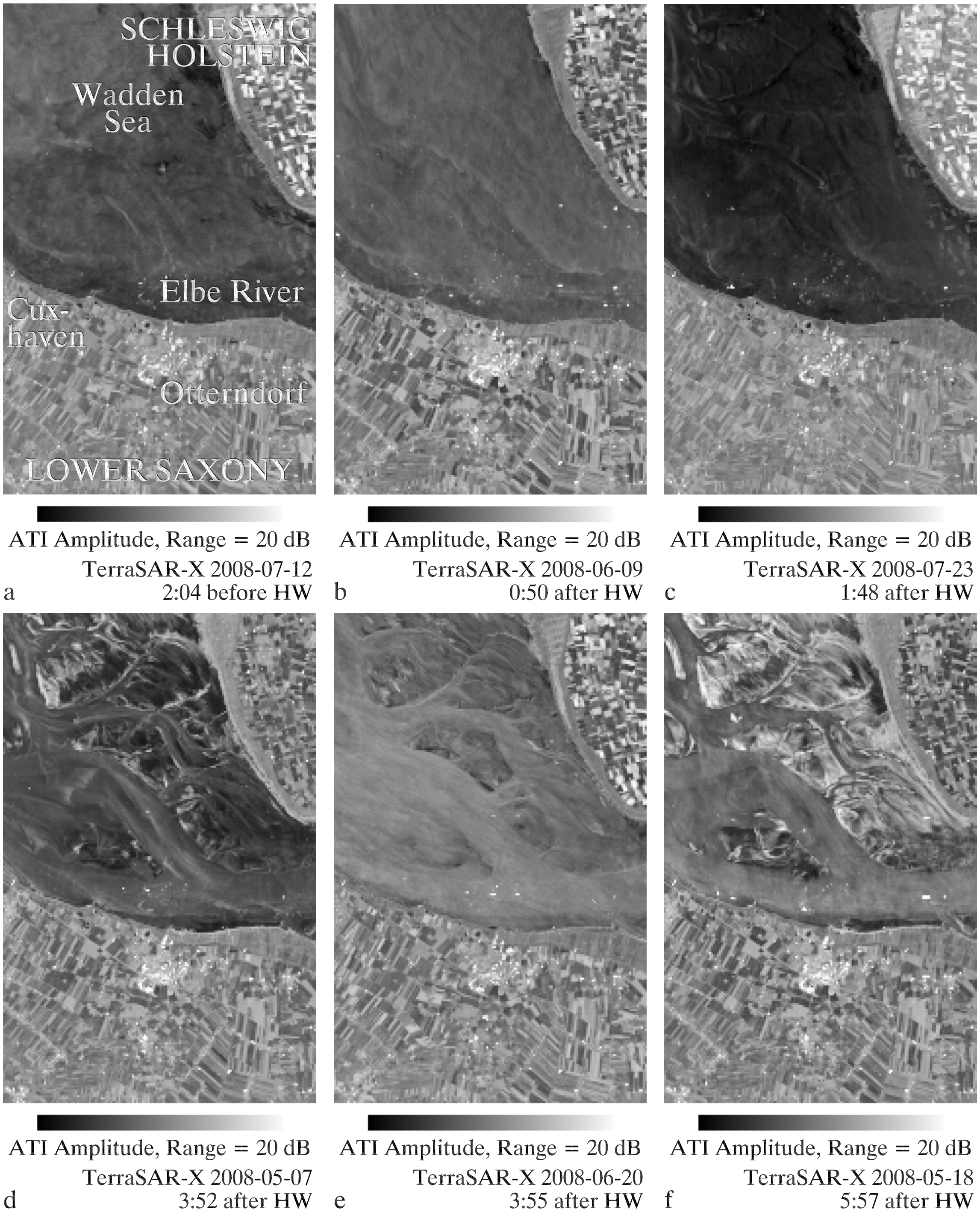

Fig. 1: Six TerraSAR-X amplitude images of the lower Elbe river (Germany) and some land north and south of it, acquired between May 5 and July 23, 2008. Total test area size is 16 km × 25 km, radar look direction is from left to right. The images were acquired at different tidal phases and under different wind conditions, thus the water levels and the brightness of the water surface are different. White pixels in the water are ships and other metal structures. The top right image exhibits pronounced ghost signatures of the fields north of the river over the water.

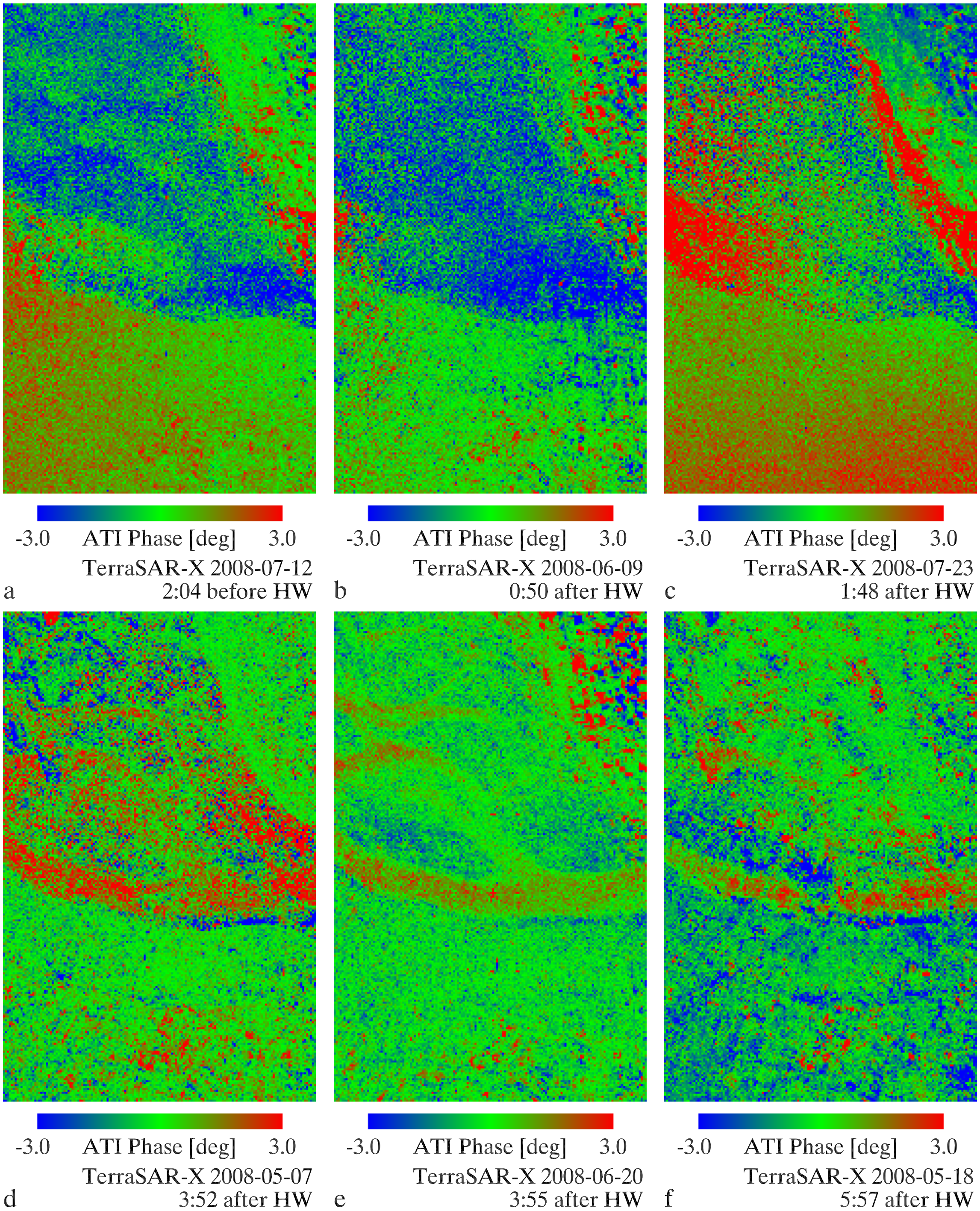

Fig. 2: Interferometric phase images corresponding to the six amplitude images of Fig. 1. The unfiltered phases look very noisy, but different dominant colors of the river indicate that the mean line-of-sight velocities are different.

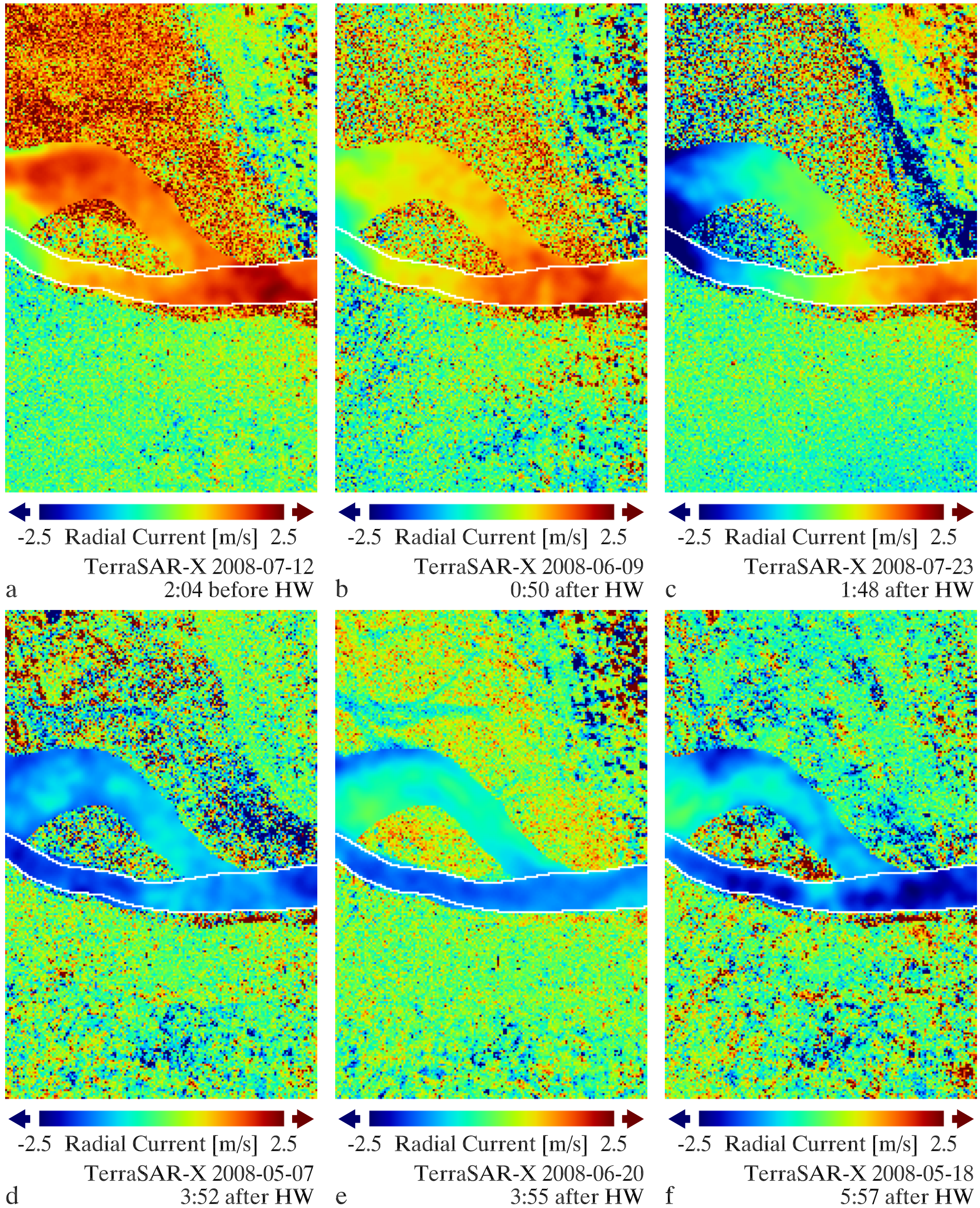

Fig. 3: Line-of-sight surface current fields in the Elbe river as obtained by converting the phase images of Fig. 2 into horizontal Doppler velocities, filtering, and applying corrections for absolute calibration and for theoretical contributions of wave motions. White lines indicate boundaries of the main test area for which statistical analyses have been carried out. Signatures over land show unfiltered zero-mean residual Doppler velocities. Due to the filtering, the current fields in the river look very smooth. Mean currents in the six cases range from about –1.7 to 1.3 m/s. The upper three images show artifacts on the left, which result from azumith ambiguities in the SAR processing.

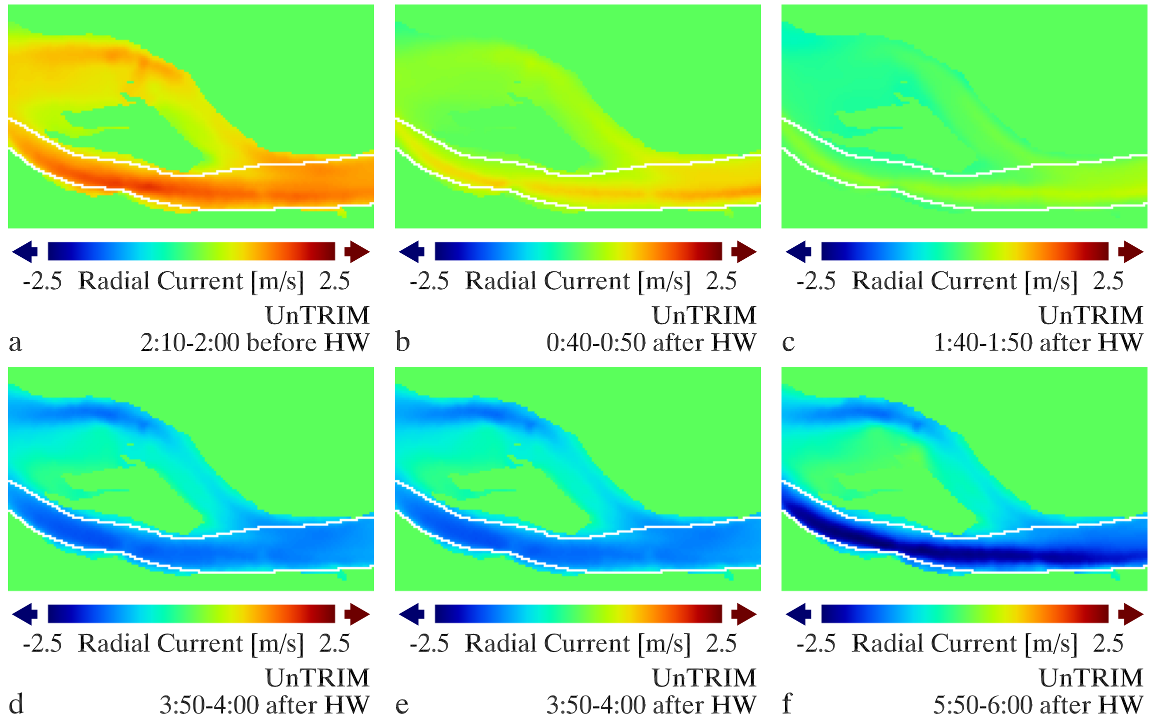

Fig. 4: Line-of-sight surface current fields in the Elbe river according to numerical model UnTRIM of the German Federal Waterways Engineering and Research Institute (BAW), for six tidal phases corresponding to the tidal phases at the times of the TerraSAR-X overpasses. The current fields look similar to the ones obtained from TerraSAR-X.

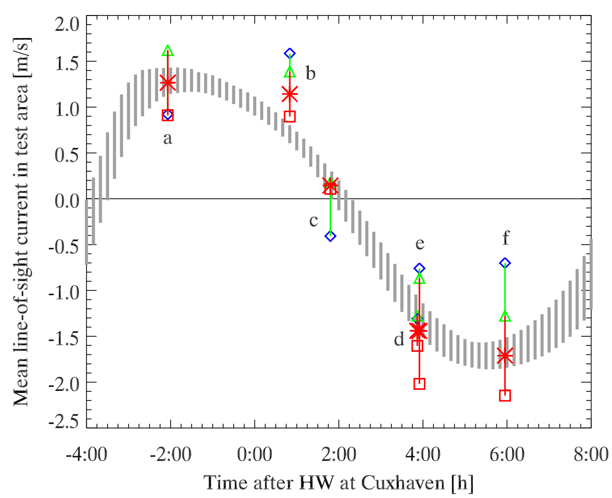

Fig. 5: Diagram showing temporal variations of spatial mean line-of-sight currents in the mean test area as function of tidal phase, according to UnTRIM (gray bars) and Terra-SAR-X. Blue diamonds show uncorrected Doppler velocities; green triangles show Doppler velocities after phase recalibration; red lines between triangles and red squares indicate theoretical maximum of corrections for wave contributions according to our model, and red asterisks show best estimates of mean currents after applying 50% of these corrections. The applied corrections lead to significant improvement, and the final results are within the bars indicating the variability of the model in five of the six cases.